(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 924 890 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.06.1999 Bulletin 1999/25

(51) Int. Cl.6: H04L 1/12

(21) Application number: 98310292.2

(22) Date of filing: 15.12.1998

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 15.12.1997 US 991587

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(54) Adaptive error correction for a communication link

(57) A method of data transfer between a transmitter and a receiver over a communications link achieves maximum throughput by dynamically adapting a coding rate, and specifically an error correction encoder, as a function of a measured reverse channel signal parameter. The method comprises the steps of transmitting a signal from the transmitter to the receiver, the receiver receiving and measuring the signal to noise ratio of the transmitted signal. The receiver determines an appropriate code rate and encoding technique as a function of the measured signal to noise ratio and transmits an encoding identifier (22) of the determined encoder to the transmitter. The transmitter encodes its data according to the encoding identifier (22) and transmits the encoded message (18) to the receiver. The receiver receives the encoded message (18) and decodes the message according to the determined code rate and encoding technique.

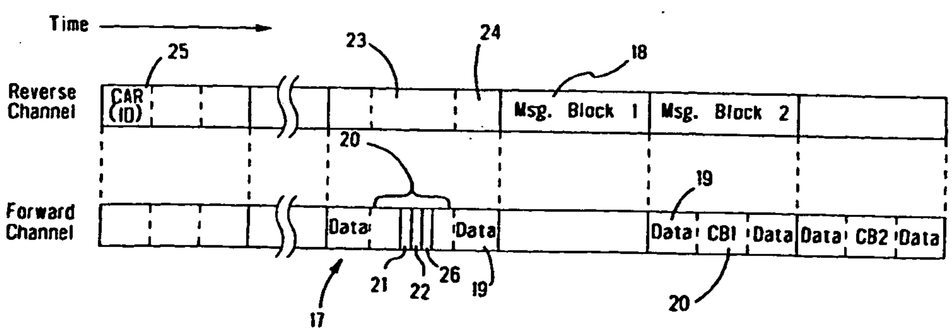

Fig. 4

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Description

[0001] The present invention relates to a method of communication over a communications link and more particularly to a method of encoding and transmitting data over an established communications link.

[0002] In an effort to increase the utility of wireless communications, advances have been made to improve the probability of transmission and receipt of error free or error correctable information. It is known that data blocks transmitted over a communications link may be encoded with one of an available plurality of error correcting encoders. The data block is encoded by the transmitting device according to a known algorithm, for example a Reed-Solomon encoder. The encoded data block is received by a receiving device which then decodes the data according to an appropriate error correcting decoder. In this case, both the transmitting device and the receiving device have a priori knowledge of the error correction coding that is in use. Advantageously, if one or more bits in the transmitted data block is corrupt, the decoder used at the receiving device may detect and correct the corrupted bits, thereby allowing use of the transmitted data block. Error correction encoders/decoders are used to increase the throughput of the communications channel by obviating the need to discard and retransmit corrupted data blocks. Disadvantageously, in order to transmit an encoded data block, a portion of the data block is used as overhead in order to transmit the information for use in decoding the subject data block. Accordingly, the portion of the data block used to transmit error correcting encoding information cannot be used to transmit bits of information, thus reducing the throughput of the communications link. The reduction in the amount of data transmitted on a per data block basis due to the error correcting overhead is, however, worthwhile in view of the increase in average throughput over time due to the ability to use data blocks that would otherwise be discarded and retransmitted.

[0003] Wireless communication is used in many areas including mobile telephone, wireless LAN, and mobile voice and data networks. Wireless communications are also used in applications where both the transmitter and the receiver are physically stationary such as digital TV. One known type of communications protocol provides access to the transmission channel without use of a reservation protocol. An example of this type of communications protocol known in the wireless communications industry is the CDPD Communication System protocol for mobile devices communicating with a base station and is defined by the CDPD System specification Release 1.1, January 1995, the contents of which are specifically incorporated by reference herein. As defined in Part 402 of the CDPD System Specification "Medium Access Control", Section 4.6, pages 402-21 through 402-24, reverse channel message blocks, which are defined as a series of data blocks transmitted from a mobile to a base station, are Reed-Solomon (63,47) encoded to improve the probability of successful transmission. Each forward and reverse channel message block is encoded based on a (63,47) Reed-Solomon code generated over a 64 bit Galois Field GF(64). The code word is based on 6-bit symbols. The information field consists of 47 6-bit symbols, comprising 282 bits, and the generated parity field consists of 16 6-bit symbols, comprising 96 bits, for a total encoded block comprising 378 bits. While the error correcting encoded data blocks provide for a more robust data transmission, the encoding scheme applied to all of the data blocks results in some sacrifice in channel throughput as compared to the theoretical maximum throughput value. In other cases, the (63,47) Reed-Solomon encoding is insufficient for successful transmission and results in a discarded transmission and retransmission. Retransmission of message blocks also adversely affects channel throughput. Since maximizing channel throughput permits increased channel traffic without an increase in communication system infrastructure, it is desirable and cost effective to maximize channel throughput.

[0004] Another known communications link that provides access to the channel through a channel arbitration process uses a (63,45) Reed-Solomon error correction encoder for transmitted data blocks. Where CDPD controls access to the reverse channel using a slotted non-persistent Digital Sense Multiple Access with Collision Detection (DSMA/CD) method, other communications links include a direct channel arbitration method whereby the mobile reguests access to the reverse channel and does not initiate a transmission of a data block on the reverse channel until the request for access to the channel is granted by the base station. Both types of communications links benefit from error correction, the optimum type and level of error correction being a function of the specific wireless network. Both types of communications links optimize average channel throughput by trading off instantaneous channel throughput in exchange for a more robust transmission by dedicating some of the data block in each datablock transmission to error correction overhead. Both types of communications links would benefit from maximizing information throughput.

[0005] There is a need, therefore, for a method to maximize the efficiency of the available bandwidth and throughput.

[0006] It is an object of an embodiment of the present invention to maximize the throughput in a communications link.

[0007] It is another object of an embodiment of the present invention to increase the range of operation of a mobile communications device without decreasing channel throughput.

[0008] A method of data transfer between a mobile and a base station over a communications link comprises the steps of the mobile transmitting a signal and the base station receiving and measuring the signal.

The base station determines an error correction algorithm as a function of the measured signal and transmits the determined error correction algorithm to the mobile. The mobile encodes a message according to the determined error correction algorithm and transmits the encoded message. The base station receives the encoded message and decodes the message according to the determined error correction algorithm.

[0009] A method of data transfer between a transmitter and a receiver, the transmitter and receiver having similar a priori knowledge of a plurality of error correction levels and the encoding information associated with the error correction levels comprising the steps of encoding a data block according to a first predetermined error correction level. The transmitter transmitting the encoded data block and the receiver receiving the encoded data block. Decoding the data block according to the first error correction level and determining whether the data block is successfully decoded. The receiver indicating to the transmitter whether the step of decoding the data block was successful or not and the transmitter changing the error correction level to a second error correction level if the step of decoding was not successful. The transmitter changing the error correction level to a third error correction level if the step of decoding was successful.

[0010] It is an advantage of an embodiment according to the teachings of the present invention that the channel throughput in a communications link is maximized.

[0011] It is an advantage of an embodiment according to the teachings of the present invention that the range of a mobile device is increased without adversely affecting the overall channel throughput.

[0012] Embodiments of the invention will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a conceptual view of a communications link between a mobile and a base station for a full duplex embodiment of a system according to the teachings of the present invention.

Figure 2 is a conceptual view of a plurality of mobiles communicating over the communications link with a single base station.

Figure 3 is a flow chart of a method of adaptively determining an appropriate data encoder for a data block transmission according to the teachings of the present invention in a communications link utilizing reverse channel arbitration.

Figure 4 is a diagrammatic view of forward and reverse channel message blocks and their relative position in time for the embodiment according to the teachings of the present invention and as shown in Figure 3 of the drawings.

Figure 5 is a flow chart of an alternate embodiment of a method of adaptively determining an appropriate data encoder for a data block transmission according to the teachings of the present invention in a communications link that does not use channel access request.

[0013] With specific reference to Figures 1 and 2 of the drawings, there is shown a base station (2) ("BS") having bi-directional communication with a plurality of mobile end stations (4) ("MES") over an established communications link (1). The communications link (1) comprises a forward channel (5) in which the base station (2) transmits information to the mobile (4) and a reverse channel in which the mobile (4) transmits information to the base station (2). In a preferred embodiment, the forward and reverse channels (5,6) occupy different bands of the spectrum, with the carrier signals separated by 45MHz, providing full-duplex communication. RF communication is achieved using frequency modulated four level Gaussian Frequency Shift Keying (GFSK), although any other modulation scheme may also be used without departing from the scope of the present invention. In a specific embodiment, the mobile (4) comprises a half-duplex radio and the base station (2) comprises a full-duplex radio. Alternate communication links are also appropriate for the present invention such as a single frequency band for both the forward and reverse channels using half-duplex radios for both the mobile (4) and the base station (2) and multiple frequency bands wherein both the mobile (4) and the base station (2) comprise full duplex radios. Both the mobile (4) and the base station (2) act as both a receiver and a transmitter. With respect to the teachings of the present invention, the transmission method could be implemented by either the mobile (4) or the base station (2). In the disclosed embodiments for a communications link having a channel arbitration process, the specific disclosure is in the context of the mobile (4) acting as the device transmitting the data block, and may be termed "a transmitter", and the base station (2) acting as the device receiving the data block, and may be termed "a receiver". For purposes of clarity and for disclosure of a specific embodiment according to the teachings of the present invention, the terms mobile 4 and base station (2) are used, and in no way limit the scope of the claimed invention.

[0014] The base station (2) communicates with multiple mobiles (4) that are geographically located within a cell, which is defined by a range of the mobile or the base station (2), whichever range limits the overall communication. A "range" is defined as the distance between which any one mobile (4) and a base station (2) can maintain a bi-directional communications link. The base station (2) generally has a higher signal transmission power, 75-100 Watts for example, as compared to the transmission power of the mobile (4), 15-30 Watts and 0.6-3.0 Watts for example. Accordingly, there is a higher likelihood, although not in all cases, of a successful transmission from the base station (2) to the mobile (4) than the mobile (4) to the base station (2). In a specific embodiment, the base station (2) encodes

forward channel message blocks (17) with a (63,45) Reed-Solomon encoder. The encoded forward channel message blocks are received and decoded by each mobile (4). Each mobile (4) may be programmed to decode any parity check or error correction encoder, the (63,45) Reed-Solomon encoder being described for illustration of a specific embodiment by way of example. The mobile (4) adaptively changes the message block coding rate as a function of measured channel characteristics. "Coding rate" is defined as a ratio of data bits relative to the total number of bits in a data block, and is always a number less than 1 and is a relative indication of overhead in a message block (18,20) transmission. In a specific example, the mobile (4) adaptively implements a (63,63-m) Reed-Solomon encoder for the reverse channel message blocks (18) in order to improve the transmission success rate from the specific mobile (4) to the base station (2). Each mobile (4) in the cell adapts its coding rate, independent of all other mobiles (4), based upon the measured signal characteristics associated with each specific mobile. Accordingly, the mobile (4) that is near to the base station (2) having a high quality communications signal has a higher coding rate and the mobile (4) far from base station having a low quality communications signal has a lower coding rate. The adaptation of the error correcting encoder is based upon signal characteristics of the reverse channel, specifically signal to noise ratio, as measured by the base station (2) and the predicted requirement of the level and/or type of error correction required for acceptable probability of a successful transmission. As an example, in order to correct up to 8 symbol errors in a 63 symbol message block transmission, 18 parity symbols are used and a (63,45) Reed-Solomon encoder is appropriate. In the (63,45) Reed-Solomon encoder, if 63 symbols are transmitted in a single message block, 45 of the symbols carry data information (23) content, and the remaining 18 symbols are error encoding/decoding information and represent overhead (24). Not all 18 symbols, however, are always needed. At any one point in time, a mobile (4) may be near to the base station (2) where the transmitted reverse channel signal is likely to have a relatively large signal to noise ratio and a relatively low number of transmission errors. In this case, a lower coding rate and thereby a lower order error correction level is appropriate, such as the (63,55) Reed-Solomon encoder, in order to increase the number of data symbols, 55 symbols in the example, and increase the throughput of the channel. Another one of the mobiles (4) may be far from the base station (2) where the transmitted reverse channel signal is likely to have a relatively low signal to noise ratio and a relatively high number of transmission errors. In this case, a higher coding rate and thereby a higher order error correction level is appropriate, such as (63,37) Reed-Solomon encoder, because the decreased amount of data symbols (23) contained in the single message block transmission due to the error correction overhead (24) is worthwhile in order to increase the probability of a successful transmission and decrease the probability of a retransmission of the specific message block. For the example having a low signal to noise ratio for the reverse channel as measured by the base station (2), the increased overhead in each data block effectively increases the information throughput by improving the transmission reliability of each message block (18) that is sent. A fixed order error correction data encoder adapted to correct the maximum number of errors expected, therefore, is not useful for all of the mobiles (4) in the cell and does not make most efficient use of the available bandwidth of the channel. Advantageously, the method according to the teachings of the present invention increases the throughput and the range of the transmitting device by dynamically adapting coding rate to the signal transmission quality of each mobile. The method, therefore, accommodates a broader range of signal transmission quality without sacrificing the data throughput for those mobiles operating under excellent signal conditions.

[0015] Generally, the number of errors in a transmission is directly related to the signal to noise ratio of the transmitted signal. The present invention proposes to dynamically adapt the type and/or level of error correction for the transmission of a data block as a function of a measured channel parameter, for example the signal to noise ratio of the received signal. The signal to noise ratio measurement may comprise a power measurement and may be made prior to signal detection. Alternatively, and in a preferred embodiment, the signal to noise ratio is made after the transmitted signal is demodulated and decoded. Signal to noise is measured as an average of the value of the departure of each received symbol from the nominal. In instances of a relatively low signal to noise ratio, a large number of errors is expected. Accordingly, the coding rate is decreased and a relatively larger portion of the data block is used as overhead to transmit error correction information. In instances of a relatively high signal to noise ratio, a small number of errors is expected. Accordingly, the coding rate is increased and a relatively smaller portion of the data block is used to transmit error correction terms. The error correction overhead is, therefore, dynamically configured as a function of the relative need for the amount of error correction to be performed.

[0016] With specific reference to Figures 3 and 4 of the drawings, there is shown a logical representation of forward and reverse channel message blocks (17,18) respectively. Each forward and reverse channel message block (17,18) is 30msec in duration. The forward and reverse channel message blocks (17, 18) are synchronous and are logically related in that the forward channel message block (17) 30 msec subsequent in time to the reverse channel message block (18) contains status information regarding the results of the transmission of the reverse channel message block (18). The reverse channel message block 18 and the

forward channel message block (17) 30 msec prior in time represent a round trip, i.e. a mobile's (4) transmission and a base station (2) response to the transmission, in the communications link 1 between the mobile (4) and the base station (2).

[0017] The forward channel message block (17) is transmitted to all mobiles (4) in the cell (15). All mobiles (4) contend for the opportunity to transmit to the base station (2) on the reverse channel (6) using one or more of the reverse channel message blocks (18). Each reverse channel message block (18), therefore, contains information content for only one mobile (4). The base station (2) transmits continuously over the forward channel (5) to all of the mobiles (4) in the cell (15) regardless of whether there is information to convey in order to maintain a communications link (1). The forward channel control block (20) consistently contains information used by all mobiles (4) in the cell.

[0018] Each forward channel message block (17) has two data blocks (19) separated in time by a control block (20). The two data blocks (19) are related in that they are logically grouped as a single block of data transmitted by the base station (2). The data blocks (19) contain digital information content. The control block (20) represents forward channel message block overhead and contains administrative information used by the mobile (4) to perform certain functions including channel access arbitration.

[0019] Each mobile (4) attempts to transmit only when it has information to convey to the base station (2). Arbitration of the reverse channel contention is performed by way of a reservation process. A portion of the control block (20) comprises a reverse channel busy status (21) (termed a "busy bit"). Typically, the mobile (4) is listening to transmissions from the base station (2) over the established communications link (1) and continuously reads and interprets information contained in each control block (20). The reverse channel (6) is often quiet and not transmitting reverse channel message blocks (18). When the mobile (4) wishes to transmit information to the base station (2), the mobile (4) monitors the value of the busy bit (21). A busy bit (21) having a zero(0) value indicates that the next 30 msec reverse channel message block (18) is unreserved ("IDLE") and will not be used by one of the mobiles (4) in the cell (15) to transmit information on the next reverse channel message block adjacent in time. Seeing that the next reverse channel message block (18) is free, the mobile (4) wishing to transmit information first sends a Channel Access Request ("CAR") over 1 of 3 randomly selected 10 msec adjacent logical microslots in the next reverse channel message block (18). As can be appreciated by one of ordinary skill in the art, when the reverse channel message block (18) is used to transmit a CAR to the base station (2), it is not used to transfer information content. Advantageously, up to three mobiles (4) are able to send a CAR on one of the reverse channel message blocks (18). The CAR comprises a randomly generated twelve bit reservation access identifier (25). When the base station (2) receives the CAR, it decodes and stores the reservation access identifier (25) and measures the signal to noise ratio of the corresponding received CAR. The signal to noise ratio of the received CAR is a reliable indication of the expected signal to noise ratio of the transmission next in time coming from the mobile (4) that initiated the CAR. Based upon the value of the signal to noise ratio, the base station (2) makes a determination as to the appropriate number of (63,63-m) Reed-Solomon error correction symbols for a reverse channel message block (18) to be transmitted by the mobile (4) at that time. As an example, for a signal to noise ratio of 15dB for a received CAR, there is a reasonable probability to expect as many as 8 errors. Using a (63,63-m) Reed-Solomon function, there are 18 error correction symbols used to correct up to 8 errors, and the appropriate encoding is a (63,45) Reed-Solomon encoder. The number of error correction symbols used is designated by the letter "m" (22) in the present specification and in the flow chart of Figure 3.

[0020] With specific reference to Figure 3 of the drawings, the mobile (4) that sent the CAR constantly monitors the control block (20) of the subsequent forward channel message blocks (17). The base station (2) grants the reservation by sending a twelve bit reservation grant identifier (26) in the control block (20) on the forward channel (5). The reservation grant identifier (26) corresponds in value to the reservation access identifier (25) of the mobile (4) to which the reservation is granted. The base station (2) also sends in the control block (20), an encoding identifier (22). In a specific example, the type of encoding used is fixed and known and the encoding identifier (22) comprises the number of error correction symbols that the mobile (4) is to use. In this specific example, the coding type is a (63,63-m) Reed-Solomon encoder. When the mobile (4) recognizes the reservation grant identifier (26) in the control block (20) in response to its CAR and identifies it as equal to the value of the reservation access identifier (25) sent by the mobile (4), the mobile (4) also receives and decodes the encoding identifier (22), specifically the number of error correction symbols to use as denoted by the variable "m" in Figure 3 of the drawings and as shown by reference numeral (22) in Figures 3 and 4 of the drawings. Based upon the number of error correction symbols to use, the mobile (4) encodes the information it has to transmit according to the specified (63,63-m) Reed-Solomon encoder and builds the reverse channel message blocks (18) accordingly. The mobile (4) transmits a burst of appropriately encoded data beginning in the next 30 msec reverse channel message block (18). Although the adaptive error correction may be performed on each block, in a specific embodiment the encoding is performed on a burst, a burst comprising up to eight consecutive message blocks (18) depending upon how much data the mobile has to convey. The base station (2) receives the series

of message blocks (18). As the base station (2) maintains the information concerning the number of error correction symbols it directs the mobile (4) to use in its encoder as indicated in the encoding identifier (22), the base station (2) decodes and corrects each data block (18) in the burst according to the (63,63-m) Reed-Solomon decoder. The base station (2) assesses whether each reverse channel message block (18) transmission succeeded or failed. The control block (20) of the forward channel message block (17) that is 30 msec subsequent to the transmitted reverse channel message block (18) containing information, indicates a receipt status to the mobile (4) with an ACKnowledge (ACK) or a No AcKnowledge (NAK) informing the mobile (4) as to whether or not the information was properly received and decoded. If the reverse channel message block (18) transmission was successful, the mobile (4) encodes the reverse channel message block (18) that is to be transmitted next in time according to the same (63,63-m) Reed-Solomon function. If the reverse channel message block (18) transmission was unsuccessful, the base station (2) issues a NAK in the appropriate control block (20) to which the mobile (4) retransmits the reverse channel message block (18) in response. The mobile (4) transmits up to eight reverse channel message blocks in a burst and uses up to twelve consecutive 30msec time slots to transmit the burst if one or more re-transmissions are necessary. During channel arbitration, instances exist when more than one mobile (4) initiates a CAR on the same microslot. In these instances, a collision occurs and both CARS are corrupted and are not received by the base station (2). If the initiating mobile (4) does not receive a reservation grant after a predetermined length of time, the mobile initiates another CAR in order to gain access to the reverse channel (6) and the communication flow proceeds as previously described.

[0021] Alternate embodiments according to the teachings of the present invention include measuring one or more reverse channel transmission parameters and determining a most appropriate one of a plurality of different error correction encoders as a function of the one or more measured reverse channel transmission parameters for a particular mobile (4). Alternate reverse channel transmission parameters include for example: absolute signal power, bit error rate and reverse channel transmission success rate. Alternate error correction algorithms include: BCH coding, Golay coding, and convolutional coding. In an alternate embodiment, the reservation grant includes the encoding identifier (22) which provides an indication of the type or level or type and level of error correction decoder to use. This embodiment is very general in that it provides the capability to dynamically adapt to any number of error correction algorithms depending upon specific characteristics of the reverse channel transmission. For example, the Reed-Solomon encoder is particularly effective for burst errors and the BCH encoder is particularly effective for random errors. Accordingly, a measurement that is indicative of the type of errors that are occurring will determine the most appropriate error correction encoder to use. An example of the implementation of an embodiment that can adapt to different coding rates and types of encoders comprises a method wherein there is a fixed number, for example six, of error correcting encoders: such as three levels of the Reed-Solomon encoder, such as (63,53) Reed-Solomon, (63,45) Reed-Solomon, and (63,37) Reed-Solomon corresponding to a low, medium, and high level of burst level error correction respectively and three levels of the BCH encoder (63,53) BCH, (63,45) BCH, and (63,37) BCH corresponding to a low, medium, and high level of random type error correction, respectively and providing a high, medium, low coding rate respectively. The base station (2) and the mobiles (4) have a priori knowledge of the predetermined error correction encoders as well as the encoding identifier associated with each of the 6 encoders which are stored in a tabular arrangement that may be accessed in a look up operation. The base station (2) measures absolute signal power of a received signal and makes a determination as to the appropriate type of error correction. Strong absolute signal power implies a Reed-Solomon encoder/decoder, while weak absolute signal power implies a BCH encoder/decoder. The base station (2) may make an additional measurement such as signal to noise ratio to assess the appropriate coding rate for the encoder selected. The reservation grant includes a symbol representing the determined encoding identifier (22), such as numeral from 1-6. The encoding is received and used by the mobile (4) to look up the appropriate encoding information which would include the coding type and the coding rate and encodes the subsequent reverse channel message block (18) accordingly. The determined encoding identifier (22) is also used by the base station to decode the received reverse channel message block (18). As one of ordinary skill in the art can appreciate, due to the tabular nature of this embodiment and the look up function performed by the base station (2) and the mobiles (4), relatively few bits are used as overhead in the control block (20) while permitting a broad range of available encoders. Other error correction encoders are within the scope of the invention, the Reed-Solomon and BCH encoders being used by way of illustration.

[0022] An alternate embodiment according to the teachings of the present invention includes provision for adapting an error correction algorithm for a system having a channel arbitration process that does not include a CAR and a reservation grant. In such a communications system, the teachings of the present invention may be implemented wherein there are a fixed plurality, three for example, of predetermined error correction levels, (63,55), (63,45), and (63,37) Reed-Solomon error correction encoder levels corresponding to low, medium, and high correction, available within the system. When the mobile (4) has data to transmit, it encodes and

sends a reverse channel message block (18) according to a default one, medium or (63,45) Reed-Solomon for example, of the predetermined default error correction levels. Optionally, the transmitter may insert an error correction level identifier into a header of the message block for additional assurances as to proper decode. With specific reference to Figure 5 of the drawings, the receiver (2) decodes the transmitted reverse channel message block (18) according to all of the predetermined error correction encoders and determines which error correction encoder(s) were decoded with correct parity. Presumably, only one of the correction level decode resulted in parity. It is possible, however, that more than one achieved parity in which case, only one is the encoder actually used. The result of the decoded message blocks having correct parity is further decoded to decipher the header bits containing the encoding identifier. The receiver (2) compares the error correction identifier against the error correction encoder(s) that achieved parity to determine whether there was a successful decode of the transmitted data block and which encoder used is identified in the error correction encoder identifier. If the decode process was successful, the receiver (2) acknowledges successful transmission to the transmitter with an ACK. The transmitter increments a counter and determines whether the counter exceeds some threshold, for example a threshold of 150 ACKs. The threshold is somewhat arbitrary and its value is optimized for the specific communications network. Generally, the value of the threshold determines when the transmitter may properly decide that a different error correction encoder is appropriate in order to increase the throughput of the existing channel. If the threshold is not exceeded, the transmitter inserts the error correction identifier into the header of the next data block to transmit and encodes the data block according to the existing error correction encoder. If the threshold is exceeded, the transmitter dynamically adapts the error correction encoder, to a less aggressive algorithm such as (63,54) Reed-Solomon for example, and resets the counter to zero. The transmitter then encodes the next data block with the new error correction encoder, transmits it to the receiver, whereby the receiver again decodes the transmitted reverse channel message block (18) according to all of the predetermined error correction level algorithms. Presumably, the error correction encoder achieving parity is the less aggressive algorithm and the process iterates for all newly transmitted message blocks. If no parity is found for any of the error correction encoders or if the error correction identifier does not match the deciphered error correction identifier for the reverse channel message block achieving parity, the decode is unsuccessful. In the event of an unsuccessful decode, the receiver (2) sends a NAK to the transmitter (4). The transmitter (4) upon receiving one or more NAKs, changes the error correction encoder and resets the ACK counter to zero. The transmitter (4) then changes the error correction level identifier in the header of the message block, encodes the data block according to the new error correction encoder, and re-transmits the reverse channel message block (18). As one of ordinary skill in the art can appreciate, a dynamically adaptive system thus described automatically converts among appropriate error correction encoders/decoders to maximize throughput on an individual transmitter level. A system according to the teachings of the present invention, therefore, dynamically optimizes itself based upon existing transmission parameters as those transmission parameters may change, thereby maximizing overall channel throughput.

[0023] Other advantages of the invention are apparent from the detailed description by way of example, and from the accompanying drawings and from the scope of the appended claims.

Claims

1. A method of data transfer between a transmitter (4) and a receiver (2) over a communications link (1) comprising the steps of the transmitter (4) transmitting an encoded signal and the receiver (2) receiving the encoded signal, and decoding the signal according to a predetermined coding scheme including the steps of:

   the receiver (2) measuring said received signal and determining an error correction encoder as a function of the measured signal,
   the receiver (2) transmitting an encoding identifier (22) of the determined error correction encoder to the transmitter (4),
   the transmitter (4) encoding a message according to the determined error correction encoder,
   the transmitter (4) transmitting the encoded message (18),
   the receiver (2) receiving the encoded message and decoding the message according to the determined error correction encoder.

2. A method according to claim 1 wherein the step of transmitting an encoding identifier (22) further comprises the step of transmitting error correction information for the determined error correction encoder to the transmitter (4).

3. A method according to claim 1 or 2 wherein the error correction encoder is a Reed-Solomon encoder and wherein the encoding identifier (22) comprises the number of Reed-Solomon errors to correct.

4. A method according to claim 1 or 2 wherein the error correction encoder is a BCH encoder and wherein the encoding identifier (22) comprises the

number of BCH errors to correct.

5. A method according to claims 1 or 2 wherein the error correction encoder is a convolutional encoder.

6. A method according to claims 1 or 2 wherein the error correction encoder is a Reed-Solomon encoder and wherein the encoding identifier (22) comprises the number of Reed-Solomon parity symbols.

7. A method according to claims 1 or 2 wherein the error correction encoder is a BCH encoder and wherein the encoding identifier (22) comprises the number of BCH parity symbols.

8. A method according to any one of claims 1 to 7 wherein the step of measuring the signal comprises measuring the signal to noise ratio of the signal transmitted by the transmitter (4) as received by the receiver (2).

9. A method according to any one of claims 1 to 7 wherein the step of measuring the signal comprises measuring the absolute signal power of the signal transmitted by the transmitter (4) as received by the receiver (2).

10. A method according to any one of claims 1 to 9 wherein the signal transmitted by the transmitter comprises a channel access request (CAR).

11. A method according to claim 10 wherein the step of transmitting the determined error correction encoder to the transmitter is performed in a response to the channel access request (CAR).

12. A method according to claim 10 or 11 wherein the response to the channel access request (CAR) also includes a reservation grant.

13. A method according to any one of claims 1 to 12 wherein the signal transmitted by the transmitter (4) is a message block (18).

14. A method according to claim 13 wherein the step of transmitting the determined error correction algorithm to the transmitter (4) is performed in a response to the transmitted message block (18).

15. A method according to any one of claims 1 to 14 wherein the step of determining the error correction encoder comprises selection of an appropriate error correction encoder from a fixed plurality of predetermined error correction encoders.

16. A method according to claim 15 wherein the transmitter (4) uses the encoding identifier (22) to acquire error correction encoder information for the determined error correction encoder from the plurality of predetermined error correction encoders.

17. A method of data transfer between a transmitter (4) and a receiver (2) over a communications link (1) comprising the steps of:

a) the transmitter (4) transmitting a channel access request signal (CAR),
(b) the receiver (2) receiving and measuring the signal to noise ratio of said channel access request signal (CAR),
(c) determining a number (m) of Reed/Solomon error correction symbols as a function of the measured signal to noise ratio,
(d) transmitting a reservation grant (26) and the determined number (m) of Reed-Solomon error correction symbols to the transmitter (4),
(e) the transmitter (4) encoding a Reed-Solomon encoded message block (18) according to the determined number (m) of Reed-Solomon error correction symbols,
(f) the transmitter (4) transmitting the encoded message block (18),
(g) the receiver (2) receiving the encoded message block (18) and decoding the message block (18) according to the determined number (m) of error correction symbols.

18. A method of data transfer between a transmitter (4) and a receiver (2), the transmitter (4) and receiver (2) having similar a priori knowledge of a plurality of error correction encoders and the error correction information associated with the error correction encoders comprising the steps of:

encoding a data block (18) according to a first predetermined error correction encoder,
the transmitter (4) transmitting the encoded data block (18),
the receiver (2) receiving the encoded data block (18),
decoding the data block (18) according to said first error correction encoder,
determining whether the data block (18) was successfully decoded,
the receiver (2) indicating to the transmitter (4) whether the step of decoding the data block (18) was successful or not,
the transmitter (4) changing the error correction encoder to a second error correction encoder if the step of decoding was unsuccessful,
the transmitter (4) changing the error correction encoder to a third error correction encoder if the step of decoding was successful.

19. A method according to claim 18 wherein the step of

decoding the data block (18) further comprises the steps of decoding the data block (18) according to all of the predetermined error correction encoders.

20. A method according to claims 18 or 19 and further comprising the step of inserting an encoding identifier (22) into the data block (18) prior to the step of transmitting the encoded data block (18).

21. A method according to claim 20 and further comprising the step of inserting an encoding identifier (22) into the data block (18) prior to the step of encoding the data block (18).

22. A method according to any one of claims 18 to 21 wherein the step of decoding the data block (18) further comprises identifying a one or more of the predetermined error correction encoders that achieved parity in the decoding step and further comprising the step of the receiver (2) deciphering the encoding identifier (22) in the data blocks (18) that were decoded for each of the one or more of the predetermined error correction encoders that achieved parity and comparing the one or more deciphered encoding identifiers (22) with the identified error correction encoder that achieved parity.

23. A method according to any one of claims 18 to 22 further comprising the steps of counting a number of consecutive indications of a successful step of decoding and the transmitter changing the error correction level if the number of consecutive indications of a successful step of decoding exceeds a predetermined threshold.

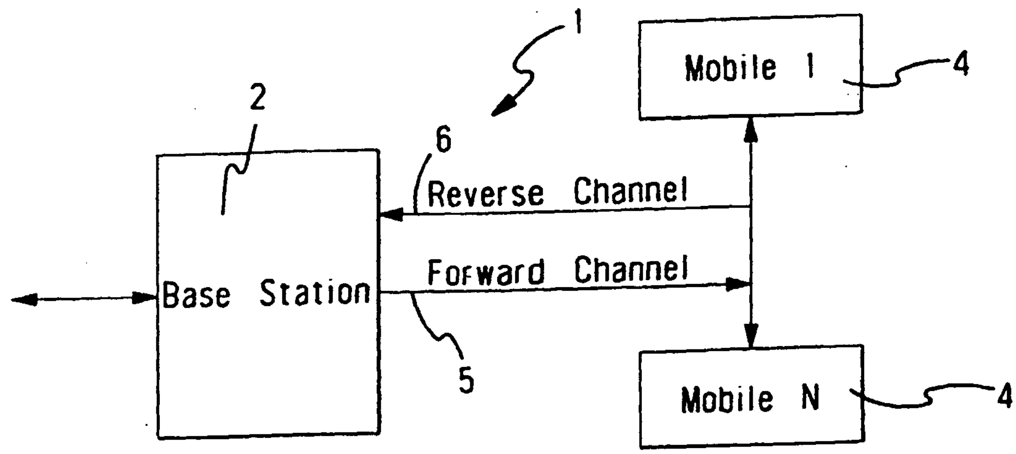
1
Mobile 1
4
2
6
Reverse Channel
Forward Channel
Base Station
5
Mobile N
4

Fig. 1

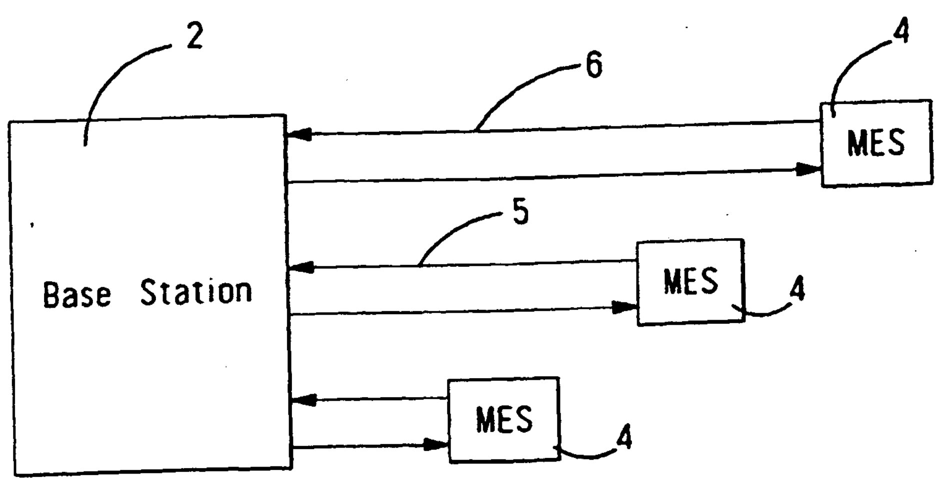
2
6
4
MES
5
Base Station
MES
4
MES
4

Fig. 2

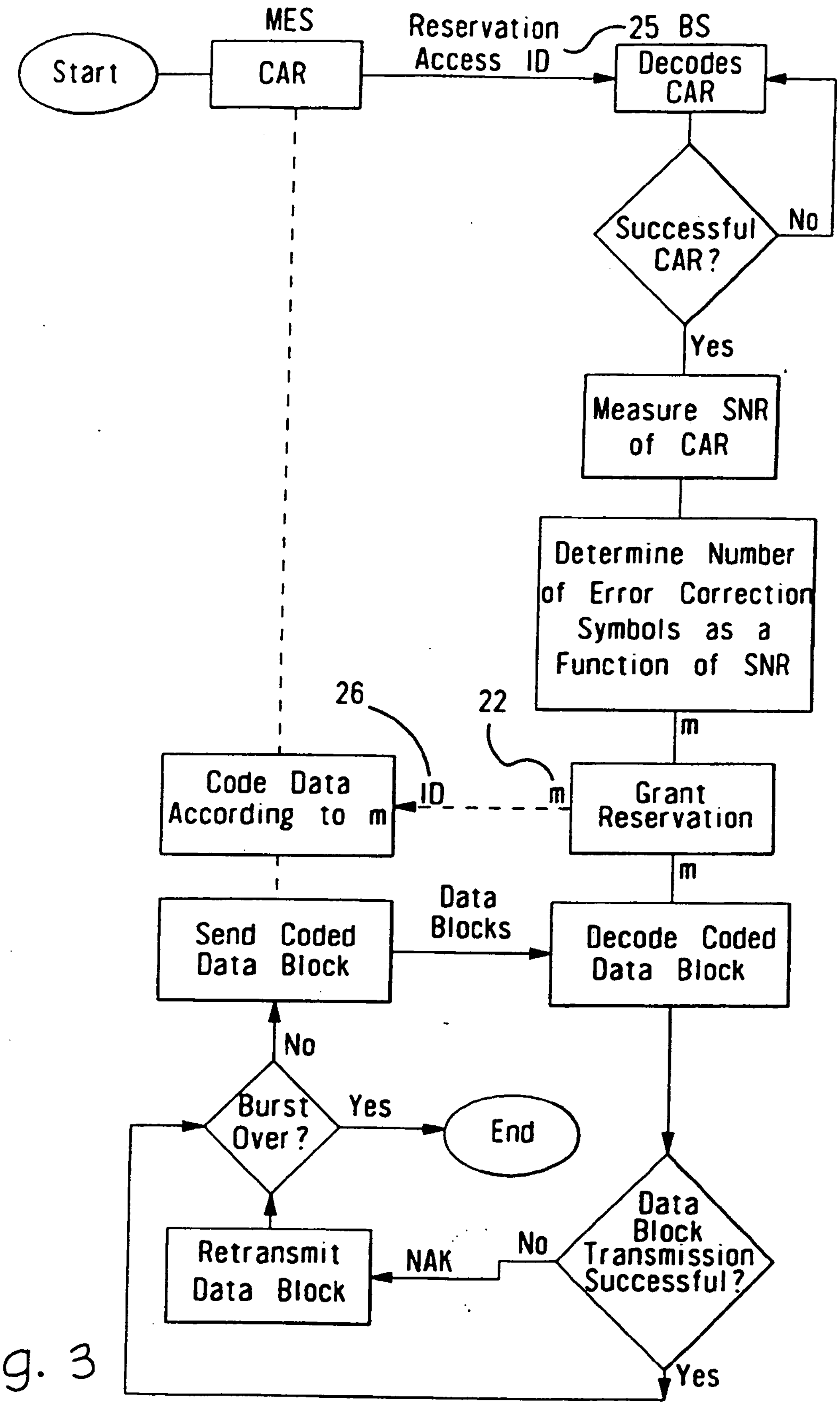
MES
Start
CAR
Reservation
Access ID
25 BS
Decodes
CAR
Successful
CAR?
No
Yes
Measure SNR
of CAR
Determine Number
of Error Correction
Symbols as a
Function of SNR
m
26
22
ID
m
Code Data
According to m
Grant
Reservation
m
Send Coded
Data Block
Data
Blocks
Decode Coded
Data Block
No
Burst
Over?
Yes
End
Data
Block
Transmission
Successful?
No
NAK
Retransmit
Data Block
Yes

Fig. 3

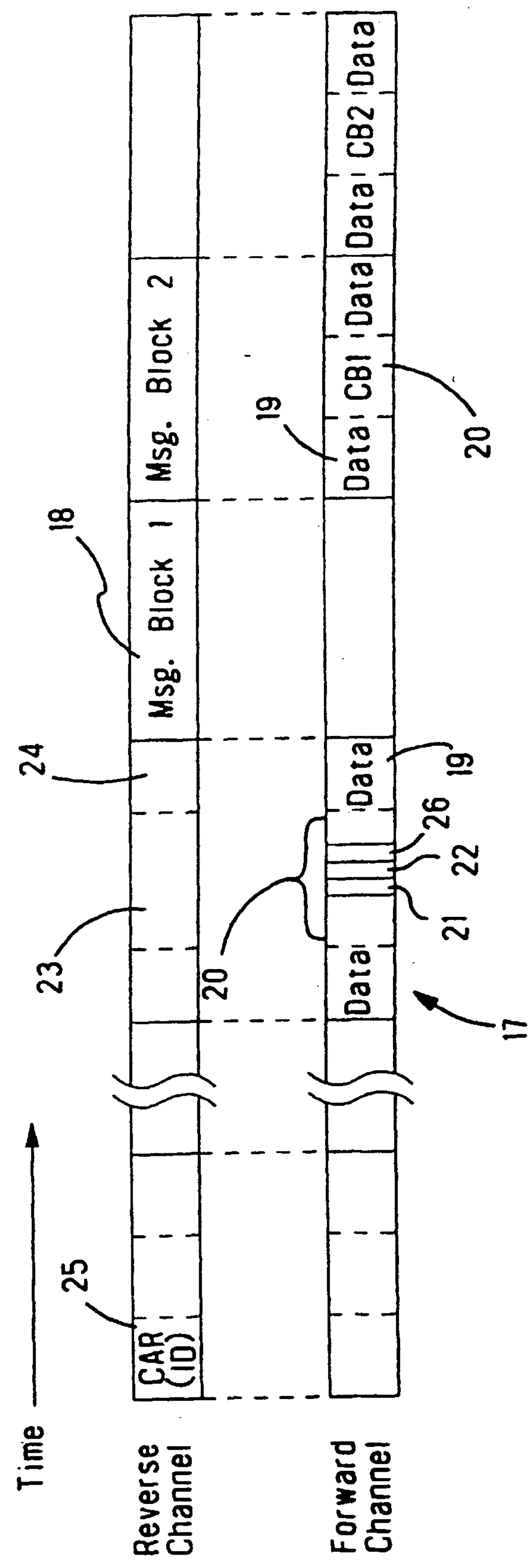
Time
Reverse Channel
Forward Channel
CAR (ID)
Msg. Block 1
Msg. Block 2
Data
Data
Data
CB1
Data
Data
CB2
Data
17
18
19
20
21
22
23
24
25
26

Fig. 4

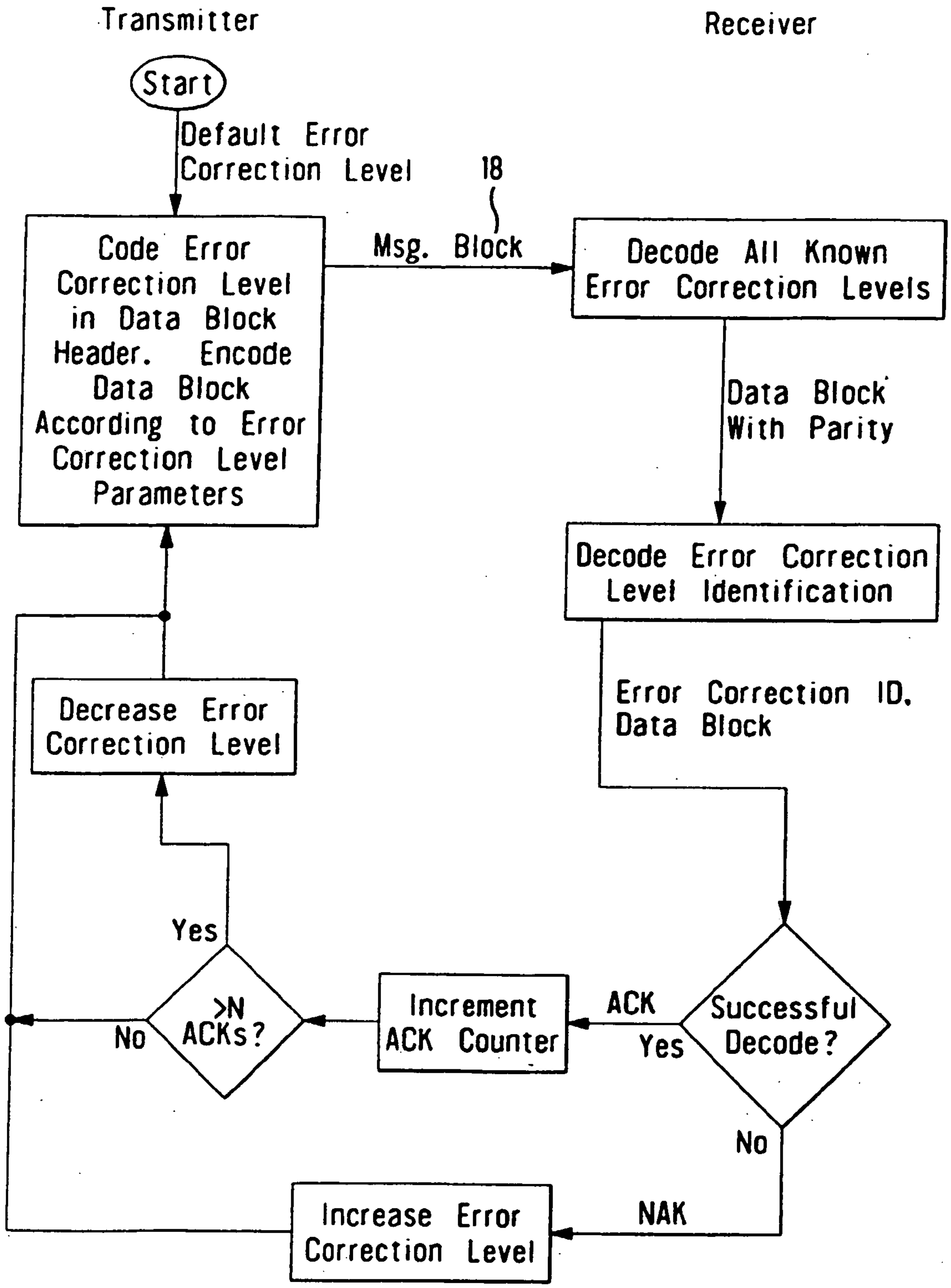
Transmitter
Receiver
Start
Default Error Correction Level
18
Msg. Block
Code Error Correction Level in Data Block Header. Encode Data Block According to Error Correction Level Parameters
Decode All Known Error Correction Levels
Data Block With Parity
Decode Error Correction Level Identification
Error Correction ID, Data Block
Decrease Error Correction Level
Yes
>N ACKs?
No
Increment ACK Counter
ACK
Yes
Successful Decode?
No
NAK
Increase Error Correction Level

Fig. 5

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 627 827 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 94107371.0

(51) Int. Cl.5: H04B 7/26

(22) Date of filing: 11.05.94

(30) Priority: 14.05.93 IT TO930335

(43) Date of publication of application:
07.12.94 Bulletin 94/49

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IT LI NL SE

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(54) **Method of controlling transmission on a same radio channel of variable-rate information streams in radio communication systems, and radio communication system using this method.**

(57) In a radio communication system, in particular a mobile communication system, variable-rate information flows originating from different sources (CV1, CS1; CV2, CS2) and relative to a same communication are transmitted on a same radio channel. Each mobile station (M1...Mh) and the fixed part (B1...Bn; RNC) of the system comprise a unit for the control of the variable-rate transmission, which dynamically allocates the available bits to the different streams by taking into account the needs of the sources (CV1, CS1; CV2, CS2), the conditions of the channel (6) and the system occupancy.

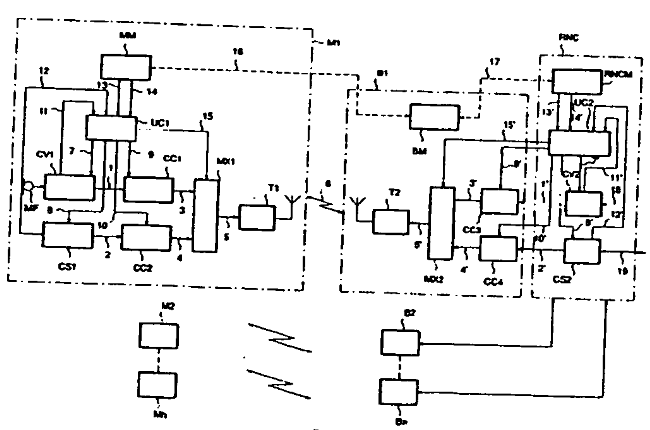


Fig. 1

EP 0 627 827 A2

The present invention relates to radio communication systems and more particularly it concerns a method of controlling transmission on the same channel of variable-rate information streams in these systems, and a system using this method.

Preferably, but not exclusively, the communication system is a mobile communication system, and the information streams are represented by coded speech signals and control signals of a speech communication on the user channel of such a system.

In the framework of research concerning future developments of mobile communications, it is being attempted to define general characteristics of systems presenting a high flexibility, so as to allow the introduction of services which today are even completely unknown or cannot be foreseen.

One example is that known as the 'Universal Mobile Telecommunications System'.

A performance which is considered as suitable is that these systems should be able to process variable-rate information streams. In fact, considering the preferred application, the two information streams (speech and control signals, meaning by the latter term both the conventional telephone signalling and the other signals, e.g. measurement results, handover commands, etc., typical of a mobile communication system) are variable-rate streams. The variability of the speech stream is due to the nature of the speech itself, the characteristics of which change during time, to the existence of pauses during a conversation, to the characteristics of the speaker, etc.

Also control signals comprise information of different nature, some of which must be transmitted periodically (e.g. results of measurements) while others (e.g. handover commands) are to be transmitted whenever necessary. Moreover, redundancy to be introduced to protect information may vary for both streams depending on the conditions of the radio channel.

Keeping this into account, access techniques to radio channels have been examined which are well suited to variable information stream processing, specially techniques of the type known as Code Division Multiple Access (CDMA). When these techniques are used, system capacity is linked to the average interference generated by active users: therefore each reduction of data transmitted at a given moment allows increasing the overall number of users served, and vice-versa, a reduction of traffic allows satisfying the requests for greater resources by certain communications.

In the case of a speech communication between a mobile station and a base station, it is possible to multiplex the two information streams, after the respective channel coding, on the same radio channel, since this solution is doubtless more efficient than the allocation of a physical channel to each stream. Considering that for each physical channel a maximum transmission rate is foreseen, which can vary depending on the system conditions, the problem arises of sharing conveniently the available bits between the two streams.

A spread spectrum communication system is already known, where two information streams at variable rates originated by two different sources (in particular speech communication traffic and communication control signals) are combined on the same physical channel. This system is described in 'Proposed EIA/TIA Wideband Spread Spectrum Standard', Qualcomm Inc., 15 May 1992, pages 6-32 to 6-42 and 7-27 to 7-83.

The known system admits four transmission rates between mobile stations and base stations, in particular 1200, 2400, 4800 and 9600 bits/s.The system can operate at anyone of the four rates when only speech signals are to be transmitted. When also control signals are to be transmitted, the system always operates at the maximum rate, keeping into account, first of all, the requirements of control signals: if these do not require all the available rate, speech signals can be transmitted too. This management system is scarcely flexible and under certain conditions it can lead to a deterioration of the speech signal quality; this deterioration could be avoided with a more sophisticated allocation criterion.

The aim of the invention is to provide a method of controlling transmission, and a system using the method, where the choice of the transmission rate is effected on the basis of a joint assessment of the needs of the individual information streams so as to keep the quality of service constant.

According to the invention, a method is therefore provided of controlling transmission on a same radio channel (in particular, a radio channel of a mobile communication system) of variable-rate information streams related to the same communication and originated by different sources, in which each stream is emitted by a source at a rate which is selected, in a given time interval, within a respective set of source rates and the stream is associated, before being sent on the channel, to a redundancy which is selected within a set of possible redundancy schemes and determines an increase of the stream rate, characterised in that, in the said interval, there are assessed the source needs in terms of the emission rate which is best suited to the stream characteristics, the channel needs in terms of the redundancy to be associated with the individual streams, and the system needs in terms of the channel rate, and each stream is allocated the emission rate and the redundancy which guarantee the attainment of a predetermined quality of the particular communication and of the service offered by the system.

The communication system utilizing the method comprises at least two stations connected via radio channels and comprising:

- sources of variable-rate information streams related to a same communication, which streams must be combined on the same radio channel, each source being able to operate, in a given time interval, at a rate chosen within a respective set of rates;
- means to introduce into each stream, in the said time interval, a redundancy chosen within a set of possible redundancy schemes, each of which causes an increase in the rate of the stream emitted by the source;
- means to combine the individual streams into a single stream to be transmitted on the channel;
- management units of the stations;

characterized in that said stations are associated with a control unit of the variable-rate streams, which unit, for each communication, receives from the sources information related to the respective needs in terms of the emission rate which is best suited to the characteristics of the respective information stream in that interval, and receives from the management units information about the needs of the channel and of the whole system during that interval, expressed in terms of redundancy to be introduced and respectively of transmission rate on the channel, and supplies the sources and the means for introducing redundancy with commands for the choice of a particular source rate and of a particular redundancy, the rates and the redundancies chosen being those which guarantee the attainment of a predetermined quality of the particular communication and of the service offered by the system.

According to a preferred embodiment of the invention, the rates and the redundancies chosen are those which meet the respective needs if the total rate resulting from the combination of the streams on the channel, expressed as the sum of the stream emission rates and the rate increments due to the redundancies, does not exceed a rate imposed by the system conditions, and otherwise each stream is allocated such an emission rate and such a redundancy as to minimize a cost of the communication, linked to the quality of the particular communication and of the service offered by the system, and given by the sum of the costs resulting from the individual needs.

Preferably, the two stations are a mobile station and a fixed part (base station and radio network control) of a mobile communication system.

The invention will be better understood with reference to the annexed drawings, where:

- Fig. 1 is a general scheme of a mobile communication system utilizing the invention;
- Fig. 2 is a block diagram of the control unit according to the invention; and
- Fig. 3 is a flow chart of the operations of the unit of Fig. 2.

In Fig. 1 the mobile communication system in which the invention is applied is schematized by a set of mobile stations M1...Mh, by a set of base stations B1...Bn, connected to the mobile stations by means of radio channels to which the stations have access according to code division techniques, and by a radio network control centre RNC.

As indicated for M1, for variable-rate speech and control signal transmission a mobile station ideally comprises:

- a speech coder CV1 which receives speech signals from microphone MF and emits on a connection 1 a coded signal at a rate r_1 generally variable frame by frame; for example CV1 can be based on analysis-by-synthesis techniques; for the purpose of the invention, CV1 constitutes the source of the respective information stream;
- a source CS1 of control signals issuing on a connection 2 a stream at a rate r_2 which is also generally variable frame by frame; in general the whole stream of control signals (hereinafter referred to also as "signaling") to be transmitted by the mobile stations to the base station will be generated locally and block CS1 schematizes the whole of the units producing this signalling;
- channel coders CC1, CC2 for speech signals and control signals, respectively, which coders receive the signals generated by CV1, CS1 and associate them with a redundancy, which in general is also variable frame by frame and results in a rate increase r_3, r_4; coders CC1, CC2 can be of any of the types used in mobile communication systems; e.g. channel coding can be based on convolutional coding.

Information streams present on outputs 3, 4 of the channel coders are combined by a multiplexer MX1 into a single stream sent through connection 5 to the CDMA transmitter T1, which forwards it on radio channel 6. MX1 and T1 incorporate all the units needed to organize the transmission according to the protocols required by the particular communication system.

Rates and redundancies r_1, r_2, r_3, r_4 to be adopted at a given time interval (e.g. a frame in a code division transmission) are communicated to blocks CV1, CS1, CC1, CC2 through connections 7-10 by a unit UC1 controlling the variable-rate transmission. UC1, which constitutes the subject matter of the invention,

communicates to MX1 also the information about total rate $r_{tot} = r_1 + r_2 + r_3 + r_4$ through connection 15. The rates are determined by UC1 keeping into account the needs of speech, signalling, channel and system.

The needs of speech and signalling can be represented by information related to the rate best suited for coding the particular speech segment or for signaling transmission in that stage. Channel conditions, which can vary both in time and depending on the position of the mobile, can be e.g. represented by information on the measured error rate, determining the protection needs of the signals and therefore the redundancy which channel coders CC1, CC2 must introduce. Finally, the system conditions, which determine the rate actually available on channel 6, depend on traffic conditions: e.g. low traffic conditions can allow a higher transmission rate for speech and therefore a better quality of the same, which can be obtained e.g. by a wide-band coding, while heavy traffic conditions can set limits to maximum data rate.

The information about the needs of CV1 and CS1 is supplied by such units to UC1 through connections 11, 12; the information related to the conditions of radio channel 6 and of the system are supplied through connections 13, 14 by a mobile station management unit MM. In general the information on the channel and on the system is not, or is not all, available to MM, which to this purpose must dialogue with the base station management unit BM, as outlined by logical connection 16.

Considering that the output quantities from UC1, i.e. the rates, are discrete quantities, it has been deemed convenient that also the input quantities should be discrete quantities, which can be represented by indices I1...I5. In particular:

- I1 ($1 \leq I1 \leq N1$) identifies which of N1 possible operating rates of the coder CV1 is best suited for speech coding in that frame; in an exemplary embodiment, seven rate values were foreseen for CV1, ranging from 400 bit/s to 16 kbit/s;
- I2 ($1 \leq I2 \leq N2$) identifies one of N2 possible transmission rates for control signals; in the said exemplary embodiment, four possible rate values were foreseen, e.g. 0, 2, 4, 8 kbit/s;
- I3, I4 ($1 \leq I3 \leq N3$ and $1 \leq I4 \leq N4$) identify one of the possible protection schemes and therefore one of the possible redundancies to be used for speech and signalling, respectively; in general, for both types of signals, the choice will be between a strong protection and a mild protection even if the same scheme uses different redundancies for the two types of signals; a single index can therefore be used to indicate the channel needs; the example considered adopted this solution with redundancies ranging from 0.6 to 11 kbits/s or from 0.6 to 15 kbits/s for speech (respectively in the case of mild or strong protection) and from 0 to 10 kbit/s or from 0 to 22 kbit/s for signalling;
- I5 ($1 \leq I5 \leq N5$) identifies one of N5 occupancy levels of the system (with level 1 corresponding to minimum occupation) and therefore one of N5 possible rates on channel 6; in the example considered, the channel rates varied between 1 kbit/s and 40 kbit/s, in steps of 1 kbit.

On the basis of this information, UC1 determines rates $r_1 ... r_4$ so as to satisfy entirely the rate and protection requirements of the different streams, if this is allowed by the system conditions; otherwise the rates are determined so as to minimize the total cost which must be paid to obtain a predetermined quality. Total cost will be represented by the sum of the costs linked with the individual needs. These costs in the described embodiment are digital values which give, for instance, an indication of the distortion associated with a certain rate of the coded signal (for speech) or with certain conditions of the channel or the system, or of the time required for the execution of a procedure (for control signals). These values can be determined a priori, e.g. by means of a simulation, and improved by field measurements during a stage of experimental running of system. Costs connected with the different needs must be normalized with respect to a common base. To simplify the realization, costs can be considered constant, and the described example refers to this case.

A possible example of cost minimization algorithm will be described with reference to Fig. 3.

A set of units similar to the one described is present also in the fixed part of the system, for managing communication towards the mobile. CV2, CS2, CC3, CC4, MX2, T2, UC2 correspond to the units CV1, CS1, CC1, CC2, MX1, T1, UC1 of the mobile; RNCM, BM are the management units of the radio network control unit and of the base station. References 1'...15' indicate connections corresponding to the connections 1...15 of the mobile.

As it can be seen, the devices concerned with the management of the communication towards the mobile are shared between the base station and the network control unit RNC. In particular, the devices more directly involved in the transmission aspects (channel coders, multiplexer, transmitter) are located in the base station; the speech coder, the control signal source and the control unit of the variable-rate transmission are located in the network control unit. The information about the channel and system conditions are supplied to UC2 by the network control management unit RNCM which dialogues with management unit BM of the base station in order both to obtain information about the channel and/or system conditions available only in BM, and to supply BM with the information about channel and/or system

conditions to be sent to MM. The logical connection between BM and RNCM is indicated by 17. Moreover in this case the control signals are partly generated locally and partly will arrive from the land network (not represented), from which the speech to be coded arrives to CV2. Connections with the land telecommunications network are indicated by 18, 19 for speech and control signals, respectively.

It should however be noted that the system organization shown in the Figure is a logical organization which is used to explain the location of the invention in the system and the operations performed by the invention, and it has no binding character on the real location of the units performing the functions described. In particular, logical connection 16 between BM and MM will be physically realized by means of an exchange of signalling through channel 6.

The receiving part, both in the mobile station and in the fixed part is not concerned by the invention and therefore it is not represented.

Fig. 2 shows the structure of a control unit UC, e.g. UC1. The unit comprises two groups of memories ME1-1, ME2-1, ME1-2, ME2-2...ME1-5, ME2-5 associated with each of the inputs, and a processing unit EL which executes the cost minimizing algorithm using the data read in the memories.

Memories ME1 store a parameter relevant to the stream rate at the output from the source, the channel coder and the multiplexer; the parameter is a vector (for the inputs associated with indices I1, I2, I5) or a matrix (for I3, I4). Memories ME2 store a matrix of costs. Considering that the emission rates and the redundancy schemes are fixed for a given configuration of the communication system and supposing that costs are constant, memories ME1, ME2 are read only memories.

Rate vectors $\overline{R1}$ = $[r_1(1), r_1(2)...r_1(N1)]$, $\overline{R2}$ = $[r_2(1)...r_2(N2)]$ and $\overline{R5}$ = $[r_5(1)...r_5(N5)]$ are vectors with N1, N2 or respectively N5 components, corresponding each to one of the possible operation rates of CV1 and CS1 or one of the N5 transmission rates on channel 6. The components are ordered according to increasing values from the first to the N1-th or N2-th for $\overline{R1}$, $\overline{R2}$, and in a decreasing order from $r_5(1)$ to $r_5(N5)$ for $\overline{R5}$. The memories are addressed at each frame by I1, I2, I5 and supply EL, through connections 21, 22, 25, with the vector component read in each of them.

Cost matrices

$$\overline{\overline{C1}} = \begin{matrix} c_1(1,1), & c_1(1,2) & \ldots & c_1(1,N1) \\ \ldots & \ldots & \ldots & \ldots \\ c_1(N1,1) & \ldots & \ldots & c_1(N1,N1) \end{matrix} \qquad \overline{\overline{C2}} = \begin{matrix} c_2(1,1), & c_2(1,2) & \ldots & c_2(1,N2) \\ \ldots & \ldots & \ldots & \ldots \\ c_2(N1,1) & \ldots & \ldots & c_2(N2,N2) \end{matrix}$$

stored in ME-1, ME-2 are addressed by rows by index I1 or respectively I2 and by columns by an index i, or respectively j, generated during the communication cost minimizing algorithm. Indices i, j can take values varying from I1 (I2) to 1, including the extreme values. Indices i, j are supplied by EL through connections 41, 42. The datum read is supplied to EL through connections 31, 32. In each row the costs decrease as the column index increases.

Costs c_1 can for example express a measure of the perceptual distortion associated with a particular combination requested rate - allocable rate. Costs c_2 can be the expression of the quality of service represented e.g. as the time for the execution of a procedure and therefore as the probability that the procedure itself could be completed in a preset time. In practice, since i, j can never exceed I1, I2, the matrices are triangular matrices, where only the values below the diagonal differ from 0; the costs on the diagonal can be allotted the value 0, where 'cost 0' means that the system is able to supply exactly the requested rate. The same convention will be adopted for the other cost matrices.

Cost matrix

$$\overline{\overline{C5}} = \begin{matrix} c5(1,1) \; \ldots\ldots \; c5(1,N5) \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ c5(N5,1) \; \ldots\ldots c5(N5,N5) \end{matrix}$$

stored in ME2-5 is addressed by index I5 for the rows and by an index Ir, associated with the total rate r_{tot} and generated during the cost minimization algorithm, for the columns. Index Ir is present on a connection 45.

It is to be noted that, when r_{tot} lies between two consecutive values of r_5, index Ir is associated with the higher value: i.e., considering that the rates in $\overline{R5}$ are decreasing, $\overline{R5}(Ir+1) < r_{tot} \leq \overline{R5}(Ir)$. Costs c_5 decrease along the rows.

In matrix

$$\overline{\overline{C5}}$$

costs c_5 (p,q) with p>q correspond to system rates greater than total rate and therefore can be considered as negative costs; the opposite for p<q. The datum read in

$$\overline{\overline{C5}}$$

is supplied to E1 through connection 35.

The third and fourth inputs are associated with memories ME1-3, ME1-4 and ME2-3, ME2-4 storing respective rate matrices

$$\overline{\overline{R3}}, \; \overline{\overline{R4}}$$

and cost matrices

$$\overline{\overline{C3}}, \; \overline{\overline{C4}}.$$

The two rate matrices

$$\overline{\overline{R3}} = \begin{matrix} r3(1,1) \; \ldots\ldots \; r3(1,N3) \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ r3(N1,1) \; \ldots\ldots \; r3(N1,N3) \end{matrix} \qquad \overline{\overline{R4}} = \begin{matrix} r4(1,1) \; \ldots \; r4(1,N4) \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ r4(N2,1) \ldots r4(N2,N4) \end{matrix}$$

contain N1 or respectively N2 rows corresponding to the N1 or N2 source rates, and N3 or respectively N4 columns (with N3 = N4 in the example considered) whose number is equal to the number of foreseen channel coding schemes. Rate values in the rows of the two matrices increase as the column index increases. Reading pointers in the two matrices are respectively I1, I2 for the rows and I3 for the columns. The datum read is presented on connections 23, 24. The two matrices are constant.

Cost matrices

$$\overline{\overline{C3}} = \begin{matrix} c3(1,1) \ldots c3(1,N3) \\ \ldots\ldots\ldots\ldots\ldots \\ c3(N3,1) \ldots c3(N3,N3) \end{matrix} \qquad \overline{\overline{C4}} = \begin{matrix} c4(1,1) \ldots c4(1,N4) \\ \ldots\ldots\ldots\ldots\ldots \\ c4(N4,1) \ldots c4(N4,N4) \end{matrix}$$

stored in ME2-3, ME2-4 are totally similar to matrices

$$\overline{\overline{C1}},\ \overline{\overline{C2}}.$$

Costs can represent a distortion introduced by the channel on the respective signal: for the speech this will be a perceptual distortion, as is the case of

$$\overline{\overline{C1}},$$

while for control signals it will be a probability that the signal could not be interpreted correctly.

The two matrices are addressed by rows by I3, while columns will be addressed by an index k, supplied by E1 through connection 43, which is generated during the cost minimization algorithm and which can vary from I3 to 1. The data read are supplied to E1 through connections 33, 34.

Figure 3 contains the flow chart of the algorithm. At each frame, the rate vector/matrix components addressed by indices I1...I5 and the values of the indices are loaded in EL (step 101). Said components are indicated as r_m (min) where m = 1,2,3,4. The corresponding total rate

$$r_{tot}(min) = \sum_{m=1}^{4} r_m(min)$$

is then determined and compared with rate r_5 permitted by the system (steps 102, 103). If r_{tot}(min) does not exceed r_5, the four rates requested are accepted and the relevant commands are emitted for blocks CV1, CS1, CC1, CC2, MX1 (CV2...MX2) (step 104).

If the total rate required exceeds system rate r_5, it is necessary to pass on to cost evaluation. Total cost of the request is initialized to a value Cmin = ∞ (step 105) and every possible rate combination, equal to or lower than those indicated by indices I1 - I4, is tested (steps 106-109). The combinations different from the initial one are obtained by diminishing the individual indices by 1 unit, independently from one another. Indices i, j, k represent the values assigned to I1, I2, I3 at a given step of the test. For each combination of i, j, k, the total rate is calculated again (step 110) and is compared now with the maximum rate admissible on the channel (step 111). If the total rate is higher than maximum rate, the only possibility is to try a combination of lower values, otherwise the cost of the combination under test will be assessed. Comparison with maximum rate and not with system rate r_5 means that the possibility is also envisaged of allocating the communication a total rate which is higher than the system rate, by paying the respective price, represented by cost c_5(I5,Ir).

For cost assessment, it is necessary to determine index Ir (step 112) and to calculate total cost Ctot, as the sum of the costs addressed in the individual matrices

$$\overline{\overline{C1}} \ldots \overline{\overline{C5}}$$

(step 113). This cost is compared with value Cmin (∞ if the initial combination is being assessed) (step 114) and whenever a total cost is lower than the one stored in memory this value is updated. Also the corresponding values $r_1...r_4$, r_{tot} are stored. At the end of the test on all the combinations of indices i, j, k, unit EL will supply values $r_1...r_4$, r_{tot} determined.

It is clear that trying all possible combinations of values of i, j, k can be effected so long as indices I1...I5 have a limited number of values, as in the example given. Under these conditions, control unit UC2 could also simultaneously manage several communications. If the number of combinations is too high, dynamic programming techniques, tree selection techniques and so on, can be used, which allow discarding beforehand a number of combinations.

It is clear that what described has been given only by way of non limiting example, and that variations and modifications are possible without going out of the scope of the invention.

For example, even if matrices

$$\overline{\overline{C1}}...\overline{\overline{C5}}$$

have been assumed to be constant for all frames, it is possible to update the values periodically. As an alternative to storage as matrices, the costs related to source and channel conditions could be organized into vectors, corresponding to the first column of the respective matrices; these vectors would vary on a frame by frame basis. Moreover, the cost vector relative to the second input would also be a function of the choice made in the preceding frames, since each choice influences the probability that the procedure can be brought to successful conclusion within the time set.

Furthermore, the invention can be applied for services other than speech transmission, such as variable-rate data transmission, in which the two streams would be represented by the data and by the signalling, or in systems employing access techniques different from CDMA but always in connection with variable-rate transmissions, e.g. PRMA (Packet Reservation Multiple Access) or ATM (Asynchronous Transfer Mode) techniques. Moreover, even if the invention has been disclosed in connection with a mobile communication system, it can be also applied to other radio communication systems comprising at least two stations connected via radio channels, in particular satellite communication systems.

Claims

1. Method of controlling transmission, on a same radio channel, of variable-rate information streams relative to the same communication and originated from different sources, in which each stream is emitted by a source (CV1, CS1; CV2, CS2) at a rate (r_1, r_2) which, in a given time interval, is chosen within a respective set of source rates and the stream is associated, before being sent on the channel (6), with a redundancy which is chosen within a set of possible redundancy schemes and which determines an increment (r_3, r_4) in the stream rate, characterized in that during the said interval there are assessed the source needs in terms of the emission rate which is best suited to the stream characteristics, the channel needs in terms of the redundancy to be associated with the individual streams, and the system needs in terms of channel rate, and each stream is allocated the emission rate and the redundancy which guarantee a predetermined quality of the particular communication and of the service offered by the system.

2. Method according to Claim 1, characterized in that each stream is allocated the emission rate and the redundancy which meet the respective needs if the total rate (r_{tot}) resulting from the combination of the streams on the channel, expressed as the sum of the stream emission rates and the rate increments due to the redundancies, does not exceed a rate (r_5) imposed by the system conditions, and otherwise each stream is allocated such an emission rate and such a redundancy as to minimize a cost of the communication, linked to the quality of the particular communication and of the service offered by the system, and given by the sum of the costs resulting from the individual needs.

3. Method according to Claim 1 or 2, characterized in that the radio channel is the communication channel between a mobile station and a base station of a mobile communication system, and the assessment of said needs is performed separately in the mobile station and in a fixed part of the system, respectively for the direction from the mobile station towards the fixed part and for the opposite direction.

4. Method according to any of Claims 1 to 3, characterized in that, for each direction of the communication, the information on said needs are represented by indices (I1...I5), linked to one of the possible source rates of each stream, to one of the possible redundancy schemes and to one of the possible channel rates.

5. Method according to Claim 4, characterized in that said indices constitute reading addresses for accessing stored information on the emission and channel transmission rates and on the rate increments caused by the redundancies, as well as on the costs associated with the rates and redundancies actually allocable.

6. Method according to Claim 5, characterized in that the information on the channel needs is represented by a single index for all information streams.

7. Method according to any of Claims 4 to 6, characterized in that the stored information relative to the source rates and to the channel rates consists of vectors with as many components ,as there are possible rate values, and the information on the rate increments caused by the redundancies is represented by matrices in which each component is associated with a combination of source/redundancy rates.

8. Method according to any of Claims 4 to 7, characterized in that the stored information relative to costs is in the form of digital values, normalized with respect to a common base and organized into matrices in which each component is associated with a combination of rates/ redundancies required and rates/redundancies allocable.

9. Method according to Claim 8, characterized in that said cost matrices are constant matrices.

10. Method according to any of Claims 4 to 7, characterized in that the information stored relative to costs related to the source and channel needs is in the form of digital values organized into vectors, updated at every time interval.

11. Method according to any preceding claim, characterized in that the information streams are digitally coded speech signals and control signals of a speech communication .

12. Method according to any of Claims 1 to 10, characterized in that the information streams are data and control signals of a variable-rate data transmission.

13. Method according to any preceding claim, characterized in that the mobile communication system is a system in which channel access occurs according to code division techniques and the transmission period on the channel is divided into frames, and in that the determination of the rate and of the redundancy to be allocated to the individual streams is made at each frame.

14. Method according to any of claims 1 to 12, characterized in that the communication system is a system in which channel access for variable-rate transmissions occurs according to time division technique.

15. Communication system including at least two stations (M1...Mh; RNC; B1...Bn) connected via radio channels and including:
   - sources (CV1, CS1; CV2, CS2) of variable-rate information streams relative to a single communication that must be combined on a single radio channel (6), each source being able to operate, in a given time interval, with a rate (r_1, r_2) chosen within a respective set of rates;
   - means (CC1, CC2; CC3, CC4) to introduce into each stream, in said time interval, a redundancy chosen from a set of possible redundancy schemes, each of which causes an increment (r_3, r_4) in the rate of the stream emitted by the source;
   - means (MX1, MX2) to combine the individual streams into a single stream to be transmitted on the channel (6);
   - management units (MM, BM, RNCM) of the stations;

   characterized in that said stations are associated with a variable-rate stream control unit (UC1, UC2) which, for each communication: receives from the sources (CV1, CS1; CV2, CS2) information on the source needs in terms of the emission rate which is best suited to the characteristics of the respective

information stream in that interval; receives from the management units (MM, RNCM) information on the needs of the channel (6) and of the entire system in that interval, expressed in terms of redundancy and respectively of transmission rate on the channel; determines a particular source rate and a particular redundancy for each stream and provides the sources (CV1, CS1; CV2, CS2) and the means (CC1, CC2; CC3, CC4) for redundancy introduction with commands for the choice of that particular source rate and redundancy, the rates and redundancies chosen being those which guarantee the attainment of a predetermined quality of the particular communication and of the service offered by the system.

16. Communication system according to Claim 15, characterized in that the rates and redundancies chosen are those which satisfy the source and channel needs in that interval, if the total rate (r_{tot}) of the stream resulting from the combination, expressed as the sum of the emission rates of the streams and the rate increments caused by the redundancies, does not exceed a rate (r_5) determined by the system conditions, while otherwise the rates and redundancies are chosen so as to minimize a total cost of the communication, linked to the quality of the particular communication and of the service offered by the system, and given by the sum of the costs resulting from the individual needs.

17. Communication system according to Claim 15 or 16, characterized in that each control unit (UC1; UC2) includes:
- a first group of memories (ME1-1...ME1-5), which store information relative to the possible rates of the streams emitted by the sources, to the combinations of each of these rates with each of the redundancies foreseen for the respective stream, and to the possible rates on the channel, and which are addressed respectively by the information on the needs of the sources (CV1, CS1; CV2, CS2), of the channel (6) and of the system supplied by the sources (CV1, CS1; CV1, CS2) and the management units (MM, RNCM), respectively;
- a second group of memories (ME2-1...ME2-5), which store information on the costs associated with the possible choices of rates of the streams flowing from the sources, of the redundancy required by the channel conditions and of the rate on the channel (6), and are addressed in reading at least by the information provided by the sources (CV1, CS1; CV2, CS2) and by the management units (MM, RNCM);
- a processing unit (EL), which receives from the sources (CV1, CS1; CV2, CS2) and from the management units (MM, RNCM) information on the source, channel and system needs, and from the first and second group of memories (ME1-1...ME1-5, ME2-1...ME2-5) information on the rates, redundancies and costs, and provides the sources (CV1, CS1; CV2, CS2) and the means (CC1...CC4) of redundancy introduction with commands for the choice of the emission rate and of the redundancy.

18. Communication system according to any of Claims 15 to 17, characterized in that the sources (CV1, CS1; CV2, CS2) and the management units (MM, RNCM) provide the information on the source, channel and system needs in the form of indices (I1...I5) which constitute reading addresses or parts of the reading addresses in said memories (ME1-1...ME2-5).

19. Communication system according to Claim 17 or 18, characterized in that, in the first group of memories (ME1-1...ME1-5), the memories (ME1-1, ME1-2, ME1-5) for the information on the source and channel needs store rate values organized into vectors, each having as many components as there are possible values for the source and channel rates, and the memories (ME1-3, ME1-4) for information on the channel needs store rate values organized into matrices in which each row is associated with one of the rate values of the respective source, and each column with one of the possible increments caused by the redundancy.

20. Communication system according to any of Claims 17 to 19, characterized in that the memories of the second group (ME2-1...ME2-5) store numerical cost values organized into matrices, and each memory location is addressed jointly by one of the said indices (I1...I5) and by a further index, generated by said processing unit (EL) during the determination of the rates and of the redundancies and associated with a rate or a redundancy that can be actually allocated to the individual streams emitted by the source or respectively to the total rate of the stream resulting from the combination.

21. Communication system according to Claim 20 characterized in that said cost matrices are constant matrices.

22. Communication system according to any of Claims 17 to 19 characterized in that the memories of the second group (ME2-1...ME2-4) storing costs related to the source and channel needs store numerical values organized into vectors, updated at each time interval.

23. Communication system according to any of Claims 15 to 22, characterized in that the information streams are speech signals coded in digital form and control signals of a speech communication.

24. Communication system according to any of Claims 15 to 22, characterized in that the information streams are data and control signals of a variable-rate data transmission.

25. Communication system according to any of Claims 15 to 24, characterized in that the communication system is a mobile communication system comprising a plurality of mobile stations (M1...Mh) and a fixed part (RNC; B1...Bn), consisting of base stations (B1...Bn) and of radio network control units (RNC), and the unit (UC1, UC2) controlling the variable rate streams is provided in each mobile station (M1...Mh) and in the fixed part (RNC; B1...Bn).

26. Communication system according to Claim 25, characterized in that the mobile communication system is a system in which channel access occurs through code division techniques.

27. Communication system according to Claim 25, characterized in that the mobile communication system is a system in which channel access for a variable-rate transmission occurs through time division techniques.

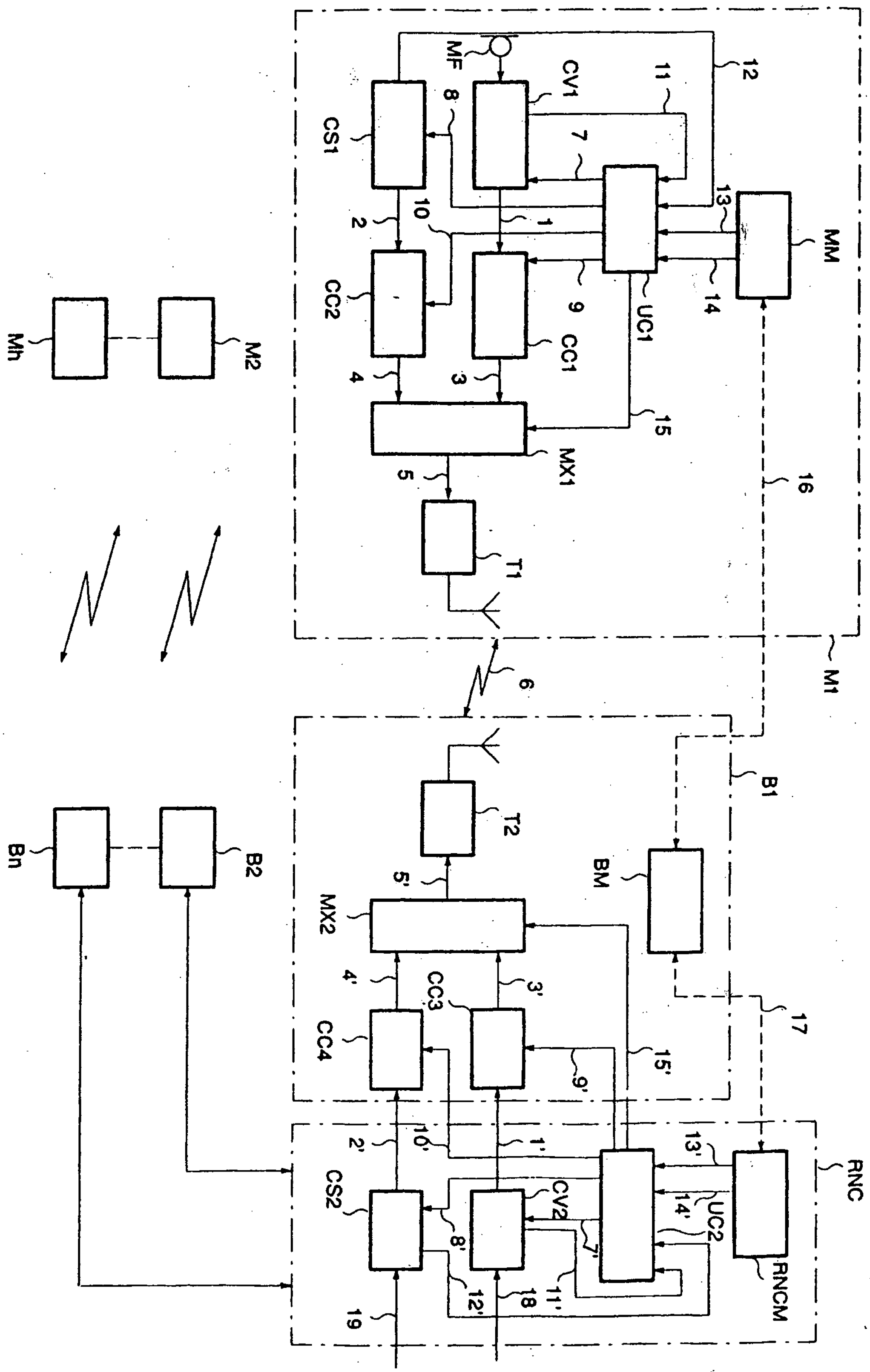

MF
CV1
CS1
11
12
7
8
2
10
1
13
MM
CC2
CC1
9
UC1
14
4
3
15
MX1
5
T1
16
M1
Mh
M2
6
B1
T2
BM
MX2
5'
4'
CC3
3'
CC4
15'
9'
17
Bn
B2
RNC
2'
10'
1'
13'
CS2
CV2
UC2
14'
8'
7'
RNCM
12'
18
11'
19

Fig. 1

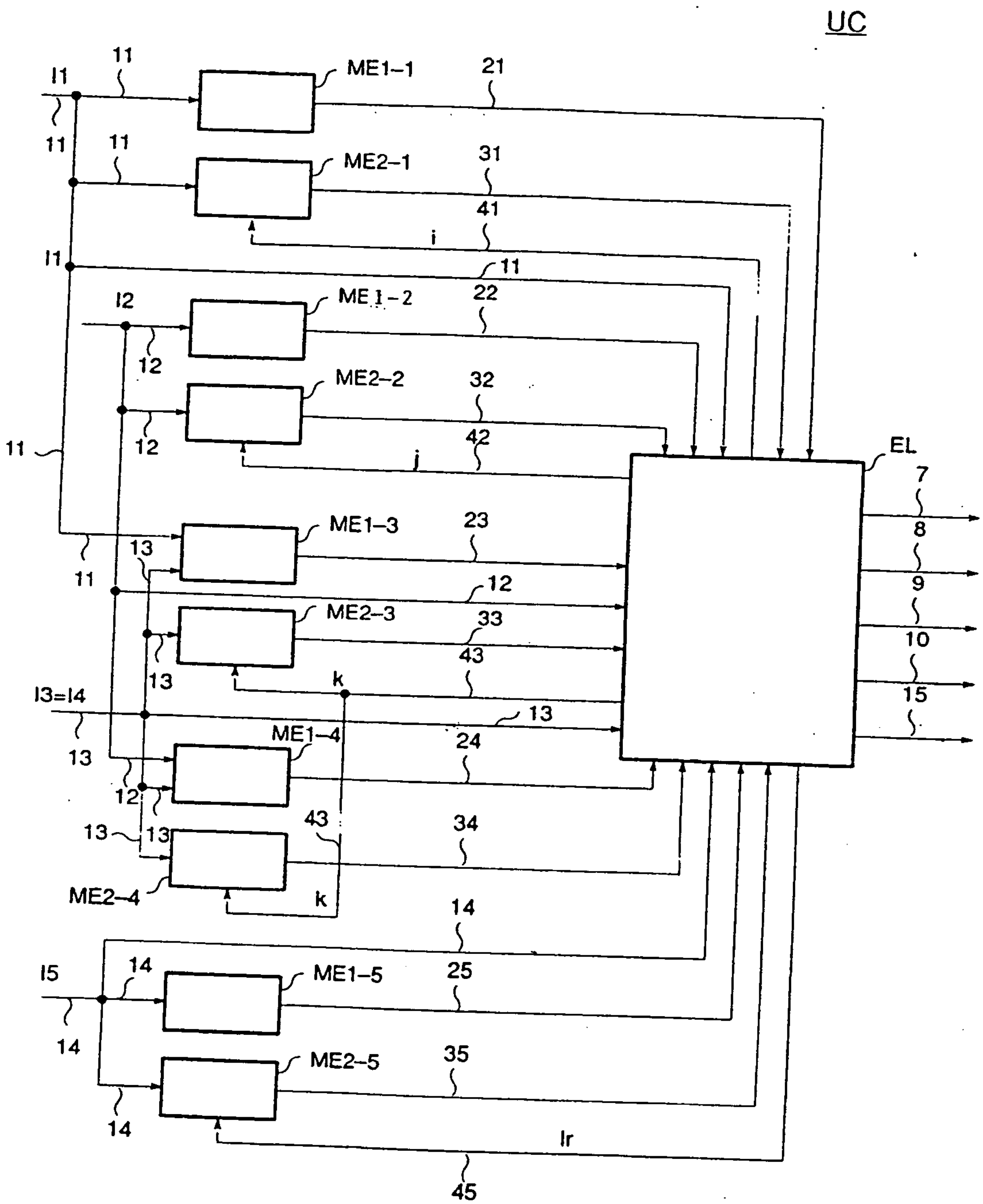
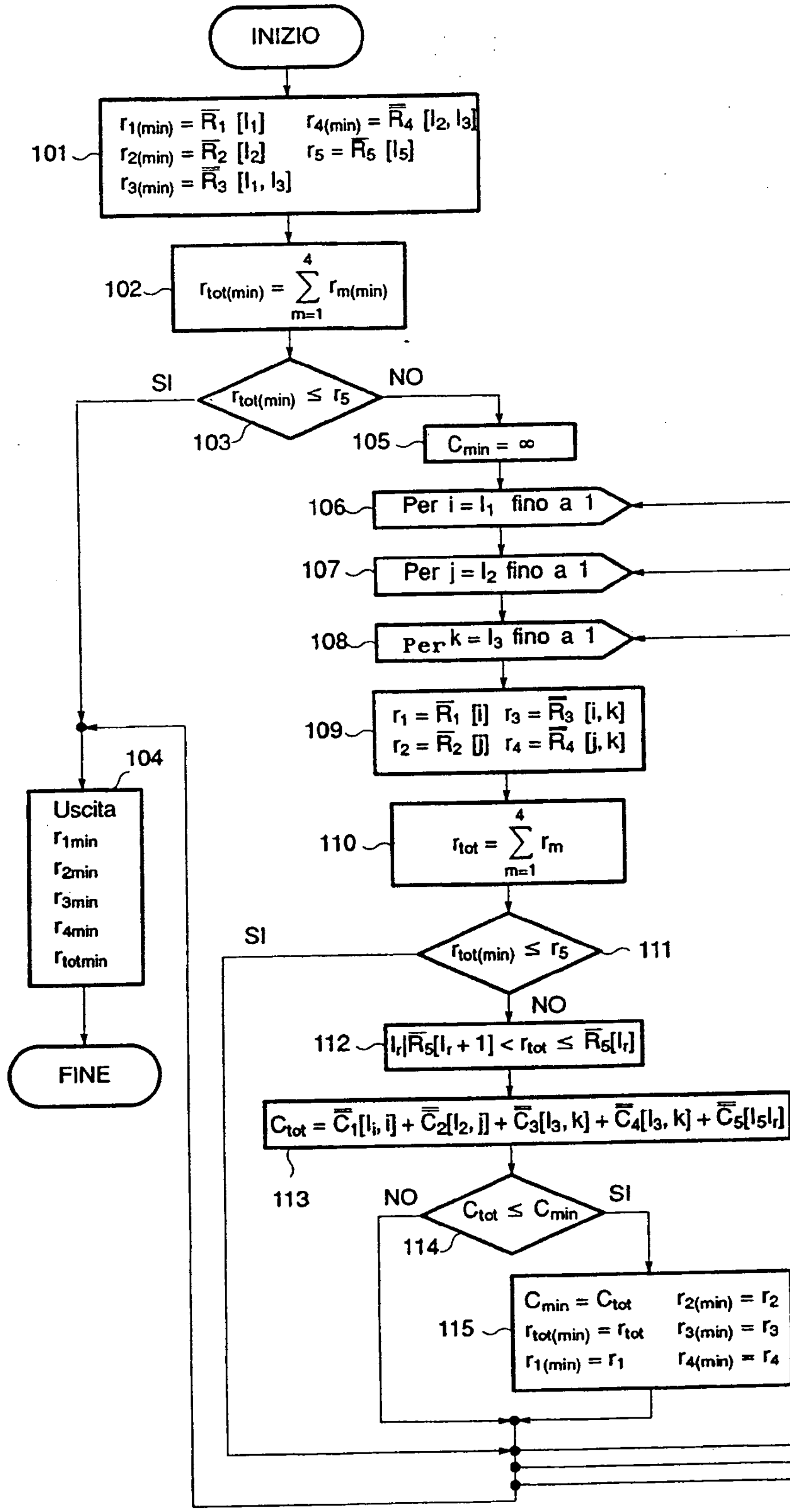

UC
I1
11
ME1–1
21
ME2–1
31
41
i
ME1–2
22
I2
12
ME2–2
32
42
j
EL
7
8
9
10
15
ME1–3
23
13
ME2–3
33
43
k
I3=I4
ME1–4
24
34
ME2–4
14
I5
ME1–5
25
ME2–5
35
Ir
45

Fig. 2



INIZIO
101
$r_{1(min)} = \overline{R}_1\,[l_1]$
$r_{2(min)} = \overline{R}_2\,[l_2]$
$r_{3(min)} = \overline{\overline{R}}_3\,[l_1, l_3]$
$r_{4(min)} = \overline{\overline{R}}_4\,[l_2, l_3]$
$r_5 = \overline{R}_5\,[l_5]$
102
$r_{tot(min)} = \sum_{m=1}^{4} r_{m(min)}$
103
$r_{tot(min)} \leq r_5$
SI
NO
104
Uscita
r_{1min}
r_{2min}
r_{3min}
r_{4min}
r_{totmin}
FINE
105
$C_{min} = \infty$
106
Per $i = l_1$ fino a 1
107
Per $j = l_2$ fino a 1
108
Per $k = l_3$ fino a 1
109
$r_1 = \overline{R}_1\,[i]$ $r_3 = \overline{\overline{R}}_3\,[i, k]$
$r_2 = \overline{R}_2\,[j]$ $r_4 = \overline{\overline{R}}_4\,[j, k]$
110
$r_{tot} = \sum_{m=1}^{4} r_m$
111
$r_{tot(min)} \leq r_5$
SI
NO
112
$l_r | \overline{R}_5[l_r + 1] < r_{tot} \leq \overline{R}_5[l_r]$
113
$C_{tot} = \overline{\overline{C}}_1[l_i, i] + \overline{\overline{C}}_2[l_2, j] + \overline{\overline{C}}_3[l_3, k] + \overline{\overline{C}}_4[l_3, k] + \overline{\overline{C}}_5[l_5 l_r]$
114
$C_{tot} \leq C_{min}$
NO
SI
115
$C_{min} = C_{tot}$
$r_{tot(min)} = r_{tot}$
$r_{1(min)} = r_1$
$r_{2(min)} = r_2$
$r_{3(min)} = r_3$
$r_{4(min)} = r_4$

Fig. 3